Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 82-83

An Analog Integrated Circuit for Motion Detection Based on Biological Correlation Model

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I. Introduction

The ability to perceive moving object is an important visual modality. An optical flow, which represents a local velocity field caused by the moving objects, has been studied in the research field of computer vision[1]. The optical flow chip has been tried to be realized by J. Kramer et al[2]. We have tried to simplify the fundamental analog integrated circuit for motion detection combining biological systems with a simplified algorithm of the optical flow. In this paper, we show experimental results of a fabricated chip which contains unit circuits for the motion detection. Results of SPICE simulations, based on those results and the simplified algorithm, showed that the proposed circuit can detect the direction and speed of motion.

II. A Simplified Algorithm for Motion Detection and Correlation Model

A local velocity $\mathbf{u}(\equiv (u,v) = (\dot{x},\dot{y}))$ in the two dimensional plane (x,y) can be obtained by minimizing the spatial integration of the following equation[1]

$$E(x,y) = \left(\nabla f \cdot \mathbf{u} + \frac{\partial f}{\partial t}\right)^2 + \lambda(u_x^2 + u_y^2 + v_x^2 + v_y^2), \quad (1)$$

where f, t, λ, $u_{x,y}$ and $v_{x,y}$ represent the intensity at a position (x,y), the time, the regularization parameter and the spatial derivations of the local velocities (u,v), respectively.

For the one dimensional motion, the local velocity u can be represented by

$$-\lambda\frac{u_{i-1} + u_{i+1} - 2u_i}{h^2} + f_{x,i}f_{t,i} = 0, \quad (2)$$

where $f_x = \partial f/\partial x$, $f_t = \partial f/\partial t$ and h the spatial constant, i the positions in x directions, as long as $2\lambda/h^2 \gg f_x^2$. The second term $f_x f_t$ in eq. (2) has a large positive or negative value around the edge of the moving object. The sign of the term depends on the direction of motion. The first term in eq. (2) means a spatial smoothing.

The correlation model of motion detection[3] for the one dimensional space is shown in Fig. 1. Each cell has an undelayed output and two delayed outputs with a time constant τ being connected with the neighboring cells. The connection to the right-hand side is excitatory and to the left-hand side is inhibitory. The value of output I_{out} represents the correlation between the undelayed output and the delayed output. Since the output cell receives inhibitory and excitatory synaptic connections from the neighboring cells, the sign of the output I_{out} is changed when the direction of motion is changed.

III. Analog Circuits for Motion Detection

Figure 2 represents a velocity sensoring circuit (VSC) which corresponds to the ith cell. A capacitance C connected in parallel with a transistor $M_{1,i}$ produces the delayed voltage $D_{\mathrm{out},i}$. The delayed voltages $D_{\mathrm{out},i-1}$ and $D_{\mathrm{out},i+1}$ from the neighboring circuits are received as $V_{\mathrm{in}+,i}$ and $V_{\mathrm{in}-,i}$, respectively. They divide the source current $I_{\mathrm{b},i}$ which is produced by the input current $I_{\mathrm{in},i}$. The output $I_{\mathrm{out},i}$ is obtained as the difference of divided currents $I_{\mathrm{in}+,i} - I_{\mathrm{in}-,i}$.

The one dimensional network is constructed by connecting VSCs, as shown in Fig. 3. The nodes of outputs are connected with a pass transistor. A following equation is obtained around the ith node.,

$$-G\,(V_{i-1} + V_{i+1} - 2V_i) + I_{\mathrm{out},i} = 0, \quad (3)$$

where V_i is the potential at the ith node and G the conductance of the pass transistor. Equation (3) has the same formula as eq. (2) of the optical flow. Thus, the potential at the ith node V_i represents the local velocity at the position i.

IV. Results

The proposed circuit was fabricated with 10μm CMOS process in Toyohashi University of Technology. The chip photograph is shown in Fig. 4.

Figure 5 represents transient responses of the VSC for $C = (50, 150, 550$ and $1050)$pF when a pulse input current was applied. The current is given to the VSC using a nMOS transistor by applying a pulse voltage V_{in} to its gate terminal. The pulse frequency, duty ratio and peak-to-peak voltage were set at 1kHz, 50% and 0-3V, respectively. The figure indicates that a large (small) C produced a large (small) time interval τ between V_{b} and the delayed voltage D_{out}.

Output currents of the VSC for the differential voltage $V_{in+} - V_{in-}$ and $V_b = (1.5, 2.0, 2.5, 3.0$ and $3.5)$V are shown in Fig. 6. The circuit showed a linear response in the range of differential voltages of $|V_{in+} - V_{in-}| < 0.5$V.

In order to confirm that the proposed circuit can produce the optical flow, we conducted the following SPICE simulation.

The result of the simulation is shown in Fig. 7 for a primitive network with $L = 100\mu$m, $d = 20\mu$m and $C = 50$pF. The output current $I_{\mathrm{out},i}$ was approximately proportional to the speed of light spot in the range between + and − maximum values s_0. The sign of the output current was changed when the direction of motion was changed. The absolute value of s_0 means the highest speed measurable. It is increased when C is reduced and d is increased.

V. Conclusion

A velocity sensoring circuit for motion detection was proposed and fabricated. Experimental results showed that the circuit could operate as expected. Results of the SPICE simulation indicated that the direction and speed of motion can be detected with the proposed network.

References

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[2] J. Kramer, R. Sarpeshkar and C. Koch, Pulse-based analog VLSI velocity sensors, *IEEE Trans. Circuits and Systems II*, vol.44, pp.86-101, 1997.

[3] W. Reichardt, *Principles of sensory communication*, Wiley, New York, 1961.

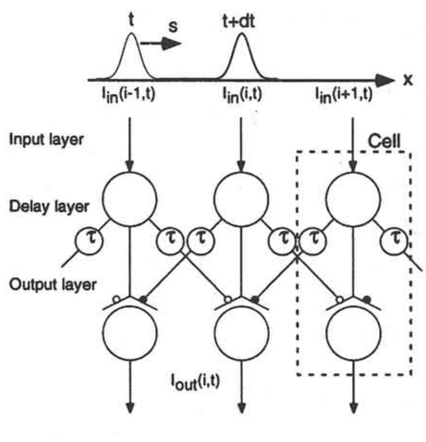

Fig. 1. The correlation model.

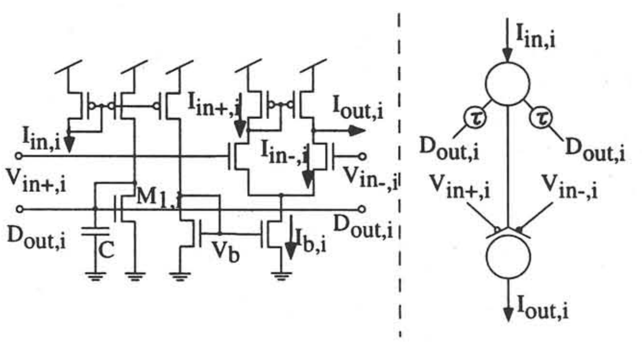

Fig. 2. Velocity sensoring circuit(VSC).

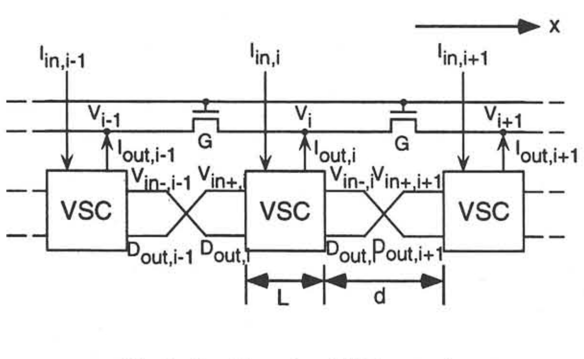

Fig. 3. One dimensional VSC network.

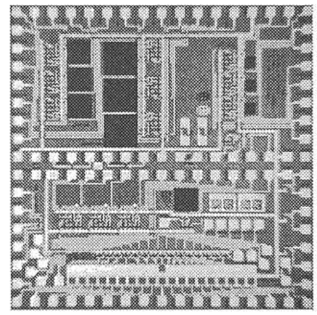

Fig. 4. The chip photograph of the VSC.

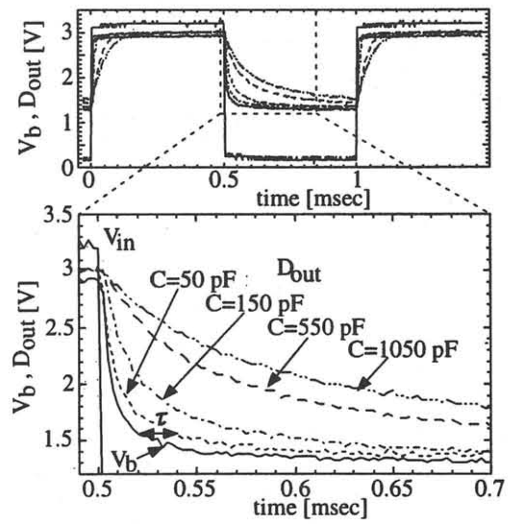

Fig. 5. Transient responses of the VSC for $C = (50, 150, 550 \text{ and } 1050)$pF.

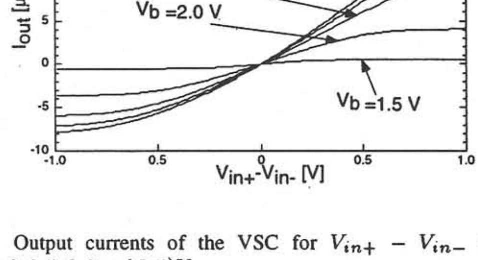

Fig. 6. Output currents of the VSC for $V_{in+} - V_{in-}$ and $V_b = (1.5, 2.0, 2.5, 3.0 \text{ and } 3.5)$V.

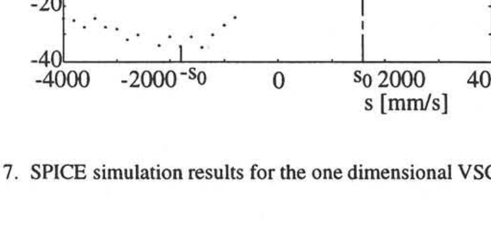

Fig. 7. SPICE simulation results for the one dimensional VSC network.